PATENT SPECIFICATION

DRAWINGS ATTACHED

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COMPLETE SPECIFICATION

Means for Measuring a Torsional Stress in a Shaft of Magnetostrictive Material

We, ALLMANNA SVENSKA ELEKTRISKA AKTIEBOLAGET, a Swedish Company, of Vasteras, Sweden, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

It is known to make use of the magnetostriction in a shaft of ferromagnetic material in order to measure the torsional stress in the shaft. According to one known method the measurement is performed by means of two magnetic cores with windings, which produce magnetic fields in the surface of the shaft, the directions of which coincide with the directions of the main mechanical stresses. When the shaft is subjected to a torsional stress its permeability increases in the direction of one of the main stresses and decreases in the direction of the other one, which causes the inductances of the windings to change. The change in the inductance is a measure of the torsional stress in the shaft and is measured by means of a measuring bridge. Due to the fact that the greater part of the reluctance lies in the air gap this method of measurement has however the disadvantage that it requires a very accurate measuring bridge and that it is very sensitive to variations in the air gap.

According to another known method of measurement, based on the magnetostrictive characteristic of the shaft, the measurement is performed by means of two magnetic circuits intersecting each other, the pole faces of which face the surface of the shaft. One of the magnetic circuits is excited by an alternating current and the other serves as a measuring device. When the shaft is subjected to a torsional stress a leakage flux is produced which induces a voltage in a winding encircling the measuring magnetic circuit. This voltage is used as a measure of the torsional stress. This method has the disadvantage that inhomogenities and irregular anisotropies in the shaft cause variations in the output voltage of the device when the shaft rotates. In order to keep these undesired voltage variations small, the base surface of the measuring device has to be so large that the faults in the shaft only influence a small portion of the active shaft surface. The base surface of the measuring device as, however, to be substantially square which causes its axial extension to become large. This is a disadvantage, as generally only spaces of small axial extension are available.

The present invention relates to an improvement of the last mentioned measuring device. By means of the invention it is possible to make the axial extension of the measuring device smaller and to obtain a measurement which is less dependent on irregularities in the shaft and shaft materials. According to the invention a means for measuring the torsion stress in a shaft of magnetostrictive material comprises two substantially equal magnetic cores having salient poles facing the shaft and being arranged side by side in the direction of the shaft and displaced circumferentially substantially half a pole pitch in relation to one another, one of said magnetic cores being provided with an excitation winding connected to an alternating current source and the other core being provided with a measuring winding connected to an electric measuring device.

The means according to the invention has a very small axial extension and it is highly insensitive to small inhomogenities and local stress concentrations in the shaft.

A device with only two cores, is, however, magnetically unsymmetrical and is therefore influenced by eddy currents generated when the shaft rotates and by the hysteresis of the shaft material. In order to eliminate these disturbances the means according to the invention preferably comprises three substantially equal magnetic cores having salient poles facing the shaft and being arranged side by side at fixed axial distances from one another, the magnetic core situated in the middle being

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provided with an excitation winding connected to an alternating current source, and the other two cores being provided with measuring windings connected to an electric measuring device.

The magnetic cores can either be shaped similarly to stator cores with poles pointing radially inwards and be intended to encircle the shaft or be shaped similarly to rotor cores with poles pointing radially outwards and be intended to be inserted in a hollow shaft.

Various embodiments of means in accordance with the invention will now be described, by way of example, with reference to the accompanying drawings, in which:—

Figure 1 is an axial view of an embodiment of the invention with two stator-shaped magnetic cores;

Figure 2 is a sectional view of the device shown in Figure 1;

Figure 3 shows the circuit diagram of the measuring device shown in Figures 1 and 2;

Figure 4 is a plane projection of the shaft surface under the poles of the measuring device shown in Figures 1 and 2 and shows the position of the poles as well as the main stresses in the shaft surface;

Figure 5 shows an embodiment of the invention with two rotor-shaped cores for measuring inside a hollow shaft;

Figure 6 is a sectional view of a device according to the invention with three stator-shaped cores;

Figure 7 shows the circuit diagram of the measuring device according to Figure 6, and

Figure 8 is a plane projection of the shaft surface under the poles of the measuring device according to Figure 6. Corresponding parts in the different figures are provided with the same reference numerals.

In Figures 1 and 2, 9 designates a shaft, the torsional stress in which is to be measured. The shaft 9 is encircled by two laminated, magnetic cores 10 and 20, provided with poles 11—14 and 21—24 respectively, which face the shaft and lie a short distance from it. The poles 11—14 and 21—24 are provided with coils 15—18 and 25—28 respectively. The device consequently resembles two stators with salient poles. The coils 15—18 of the magnetic core 10 are connected in series or in parallel, to an alternating current source and have alternate winding directions so that the poles 11—14 have alternate magnetic polarities. The coils 25—28 of the magnetic core 20 are, in a similar manner, connected to an electric measuring device. The circuit diagram of the measuring device is shown in Figure 3, in which 40 designates the alternating current source and 41 the electric measuring device.

The two magnetic cores 10 and 20 are stationary, are arranged at a short axial distance from one another and are displaced half a pole pitch in relation to one another. The poles 11—14 and 21—24 of the magnetic cores 10 and 20 consequently have a mutual position as shown in Figure 4.

The poles 11—14 have alternate polarities and produce in pairs, congruent magnetic fields in the shaft surface as long as the shaft 9 is not subjected to any stress. Due to the fact that the poles 21—24 are displaced half a pole pitch in relation to the poles 11—14 they will be positioned adjacent to points having the same magnetic potential. Due to this no magnetic flux from the shaft 9 flows through the core 20 and consequently no voltage is induced in the coils 25—28 connected to the measuring instrument 41.

When the shaft 9 is exposed to a torsional stress the magnetic stresses in the shaft may be divided into two perpendicular main stresses, one of them a tension stress σ and the other a compressive stress $-\sigma$, the directions of which are inclined at an angle of 45° to the axis of the shaft. These stresses are shown in Figure 4. Due to the magnetostrictive qualities of the shaft material the permeability in the shaft surface increases in the direction of one of the main stresses σ and decreases in the direction of the perpendicular main stress $-\sigma$. This causes the magnetic field from the magnetic core 10 to be deformed so that the difference in the magnetic potential between the pole pairs 12,22: 13,23: 14,24: 11,21 decreases and increases between the pole pairs 11,22: 12,23: 13,24: 14,25. Consequently, the poles 21—24 of the core 20 will be positioned adjacent to points having different magnetic potentials so that a magnetic flux flows through the poles 21—24 and induces a voltage in the corresponding windings 25—28 which causes a current to flow through the measuring instrument 41. A torsional stress in the shaft consequently has the same effect on the measuring instrument 41 as a displacement of the core 20 in relation to the core 10. Within the measuring range of the device the deflection of the instrument 41 is proportional to the torsional stress in the shaft 9.

It is evident from the figures that the measuring device may have a very small axial length despite the fact that it entirely encircles the shaft. Due to the fact that all mechanical stresses in a closed annular path of the shaft surface permanently take part in the measurement, small inhomogenities and stress concentrations will remain within the measuring zone when the shaft rotates, because of which their injurious influence upon the measurement will be much smaller than in the measuring devices hitherto known. The meausring device is also of an extremely simple and rigid construction.

If the shaft 9 is hollow the torsional stresses can also be measured from the inner surface of the shaft. In order to perform such a measurement the stator-shaped device described above is substituted by a rotor-shaped measuring

device having a corresponding construction and mode of action. Such a device is shown in Figure 5 in which the reference numerals used in Figures 1—4 are provided with primes.

Since the devices described with reference to Figures 1 to 5 are unsymmetrical from the magnetic point of view, an undesired influence is produced by the hysteresis of the shaft material and by eddy currents. This influence can be avoided if the device is provided with three cores so that it becomes symmetrical as shown in Figures 6, 7 and 8.

Figure 6 shows three stator-shaped cores 10, 20 and 30 which encircle a shaft. These magnetic cores 10, 20 and 30 are provided with four poles each, 11—14, 21—24 and 31—34, respectively. The poles 11—14, 21—24 and 31—34 lie at a small distance from the shaft and are provided with coils 15—18, 25—28 and 35—38, respectively. The coils 15—18 on the magnetic core 10 are connected in series or in parallel to an alternating current source and have alternate winding directions so that the poles 11—14 have alternate magnetic polarities. The coils 25—28 on the magnetic core 20 and 35—38 on the magnetic core 30 are, in a similar manner, connected to an electrical measuring device. The circuit diagram of the device is shown in Figure 7, in which 40 designates the alternating current source and 41 designates the measuring instrument. The magnetic cores 10, 20 and 30 are arranged at a small axial distance from one another and the cores 20 and 30 are displaced half a pole pitch in relation to the core 10. The mutual position of the poles is shown in Figure 8.

The device according to the Figures 6, 7 and 8 operates fundamentally in the same way as the device of Figures 1, 2, 3 and 4. When the shaft is subjected to no stress the poles 21—24 and 31—34 lie adjacent to points having the same magnetic potential, because of which no magnetic flux flows through the magnetic cores 20 and 30 and consequently no voltage is induced in the windings 25—28 and 35—38 connected to the measuring instrument 41.

When the shaft is exposed to torsional stress the magnetic field from the magnetic core 10 is deformed due to the mechanical stresses σ and $-\sigma$ and to the magnetostrictive qualities of the shaft material so that the difference in the magnetic potential between the pole pairs 11,21: 12,22: 13,23: 14,24: 11,34: 12,31: 13,32: 14,33 decreases and increases between the pole pairs 11,24: 12,21: 13,22: 14,23: 11,31: 12,32: 13,33: 14,34. Due to this the poles 21—24 and 31—34 of the cores 20 and 30 respectively, will be positioned in pairs, adjacent to points with different magnetic potential so that a flux flows through the poles and induces a voltage in the windings 25—28 and 35—38, which causes a current to flow through the measuring instrument 41. Within the measuring range of the device the deflection of the instrument 41 is proportional to the torsional stress in the shaft 9, if the excitation from the poles 11—14 has a suitable value.

A device with three magnetic cores can of course also be constructed according to Figure 5 with rotor-shaped cores intended to be inserted in a hollow shaft.

The embodiments of the invention shown in the drawing are especially advantageous but several other embodiments are also possible. It is, for example, unnecessary for the magnetic cores entirely to encircle the shaft, since the measurement can be performed by segments of the cores, provided that the segment of the core 10 has at least three poles and the segments of the cores 20 and 30 have at least two poles each. The magnetic cores may of course be divided into two or more portions in order to obtain a simpler assemblage and the number of poles may be varied without changing the mode of operation of the device.

In order to make the device insensitive to external magnetic fields, iron masses, etc., it should be provided with a magnetic shielding.

WHAT WE CLAIM IS:—

1. Means for measuring a torsional stress in a shaft of magnetostrictive material, characterised in that it comprises two substantially equal magnetic cores having salient poles facing said shaft, and being arranged side by side at a fixed axial distance from one another and displaced circumferentially in relation to one another substantially half a pole pitch, one of said cores being provided with an excitation winding connected to an alternating current source and the other core being provided with a measuring winding connected to an electric measuring device.

2. Means according to Claim 1, characterised in that it comprises three substantially equal magnetic cores having salient poles facing said shaft, and being arranged side by side at fixed axial distances from one another, the core situated in the middle being provided with an excitation winding connected to an alternating current source and the other two cores being provided with measuring windings connected to an electric measuring device.

3. Means according to Claim 1 or 2, characterised in that the magnetic cores are shaped similarly to stator cores with salient poles pointing radially inwards and that the cores are intended to encircle the shaft.

4. Means according to Claim 1 or 2, characterised in that the magnetic cores are shaped similarly to rotor cores with salient poles pointing radially outwards and that the cores are intended to be inserted in a hollow shaft.

5. Means according to Claim 3, characterised in that the magnetic cores consist of ring

sectors with salient poles and only partially encircle the shaft.

6. Means for measuring a torsional stress in a shaft of magnetostrictive material, constructed and arranged substantially as herein described and shown in Figures 1 to 4, Figure 5, or Figures 6 to 8 of the accompanying drawings.

J. Y. & G. W. JOHNSON,
47, Lincoln's Inn Fields, London, W.C.2,
Chartered Patent Agents.

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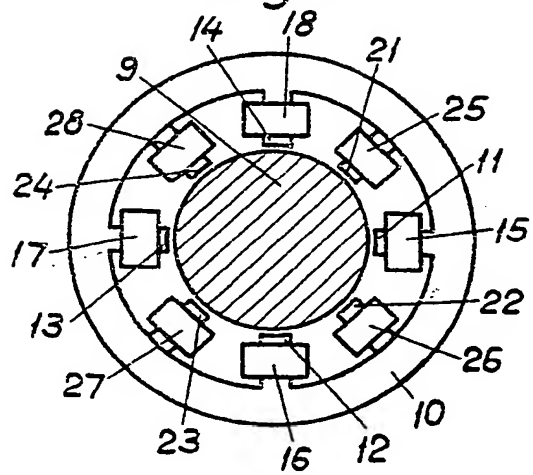
Fig.1



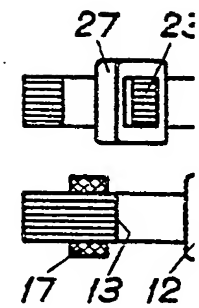
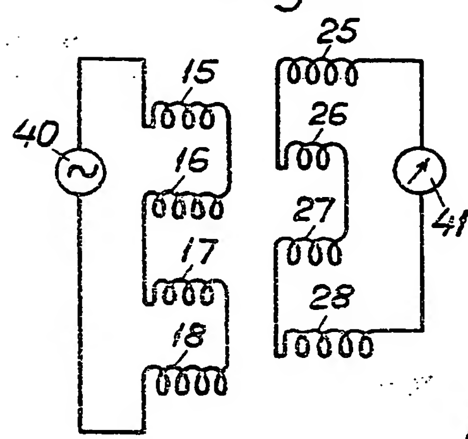


Fig.3



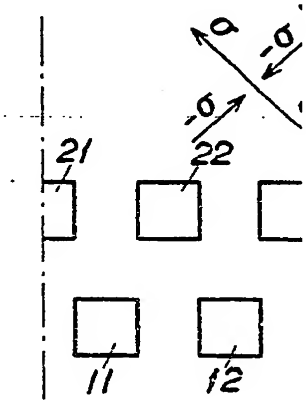
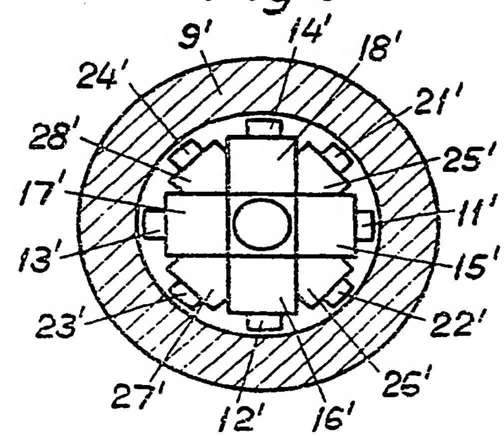


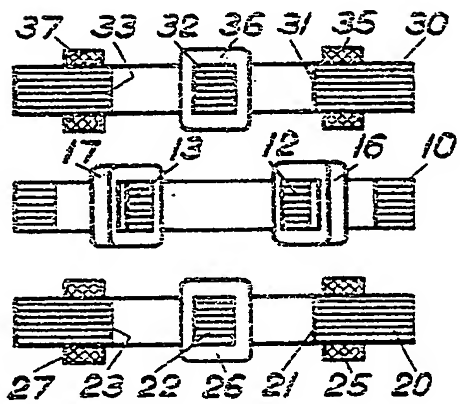
Fig.5



829,399 COMPLETE SPECIFICATION
2 SHEETS

This drawing is a reproduction of the Original on a reduced scale.
SHEETS 1 & 2

Fig.6



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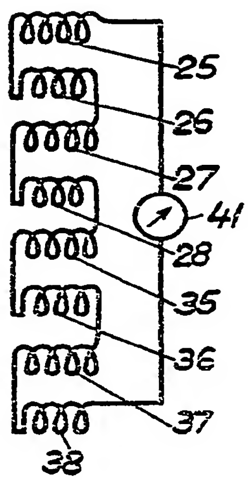

Fig.8

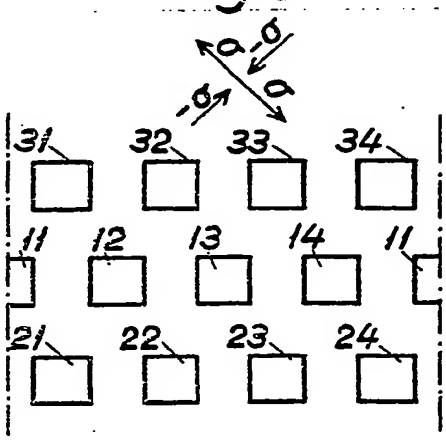

Fig.1

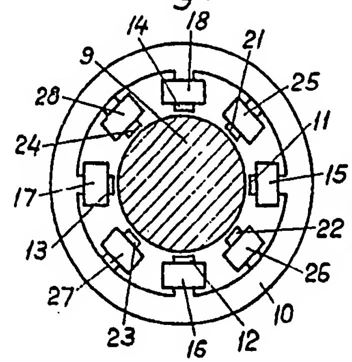

Fig.2

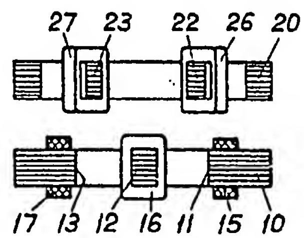

Fig.3

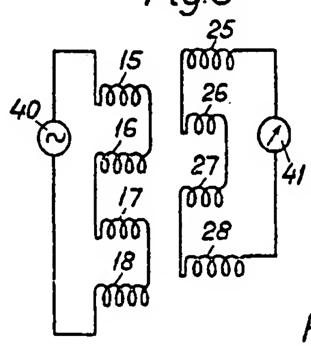

Fig.4

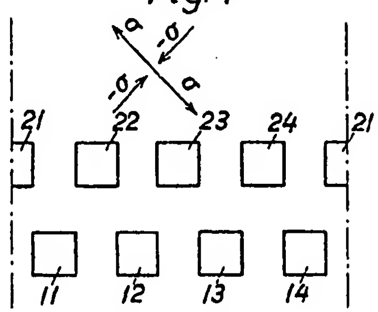

Fig.5

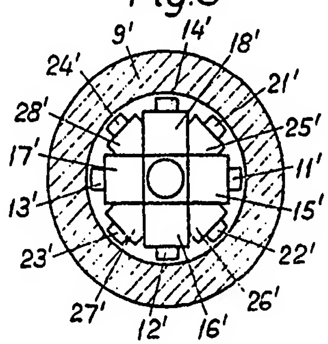

Fig.6

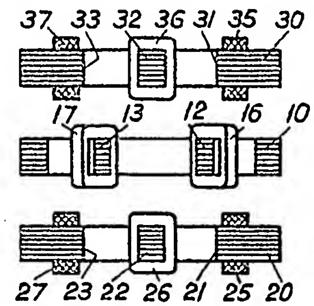

Fig.7

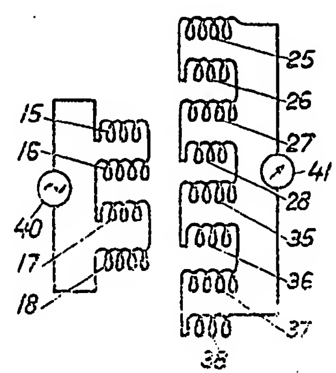

Fig.8